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(81)	Designerade stater Designated states	AP: all, EA: all, EP: all, OA: all, AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LI, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZM, ZW
(21)	Patentansökningsnummer Patent application number	PCT SE02/01183
(86)	Ingivningsdatum Date of filing	2002-06-19
(30)	Prioritet begärd från Priority claimed from	2001-07-12 US 60/304,872 2001-12-21 SE 0104409-8

Stockholm, 2004-02-12

För Patent- och registreringsverket
For the Patent- and Registration Office

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SOLENOID CONTROL SYSTEM AND METHOD FOR VEHICLE FUEL-INJECTION

BACKGROUND OF THE INVENTION

In order to minimize the exhaust of particles and nitrous oxide (NOx), as well as to achieve the highest possible efficiency in a diesel engine, the crank angle position at which fuel-injection into a cylinder of a vehicle engine is initiated is critical. Because such fuel injection is typically controlled by a solenoid valve, it is not enough to ensure that the control signal occurs at the correct position; rather one must also know when the valve itself has reached its fully opened position. One known method for determining this involves measuring the current in the driving stage of the solenoid and therefrom detecting the change in inductance that arises when the valve cone is seated. This method is usually referred to as BIP-detection, where BIP stands for "Beginning of Injection Pulse."

Figure 1 is a diagram of current and voltage as functions of time as used in the conventional BIP technique. In principle, the solenoid is controlled by applying a voltage pulse U until the current in the solenoid winding reaches a predetermined level known as the "pull-in" current, which is the current level that must be achieved in the circuit in order to be able to move the solenoid armature.

Thereafter, the control voltage U is pulsed so that the winding current remains approximately at this level until the valve is fully opened. Once the valve is fully open, however, a significantly lower current -- the so-called "hold" current -- is needed in order to keep the valve open. This hold current is also maintained by pulsing the control voltage U. The hold current is maintained until it is once again time to close the valve, which is determined by the amount of fuel that is to be injected.

Detecting the BIP signal at the same time as the pull-in current is being regulated is very difficult because the BIP signal is typically obscured by the noise that arises when using such pure current regulation. The application of the pull-in current is therefore usually turned off immediately before the time when the BIP signal is expected to arise, which can be estimated using known methods. The BIP signal (which appears as a "bump" in

the current curve) then occurs in the period during which the current discharges through a freewheel diode D connected to the solenoid winding. This period of current "decay" is known as the BIP "window." The minimum width of the BIP window needed for reliable detection of the BIP using standard equipment is typically about 600 µs.

"Freewheeling" refers to the remaining current that circulates within the solenoid circuit after the applied voltage has been shut off. If there were no resistive losses in this circuit, the freewheeling could theoretically continue forever. Components such as a freewheeling diode D and at least one resistive shunt are usually included in the solenoid circuitry, however. It has, moreover, also been shown that the time it takes for the solenoid current to decrease from the pull-in level to the hold level can vary greatly in practice, primarily because of resistances in the network of conductors (such as cables) and connectors used to connect the various components in the circuitry involved in operating the solenoid. These conductor resistances vary not only from application to application, but even among different valves in the same engine. The time for BIP detection may therefore be too short, such that it may become impossible to detect the occurrence of the BIP with certainty -- the BIP pulse may fall outside the BIP window and disappear in the noise created by the current regulation.

The main components of a typical prior art circuit that implements current-only control are shown in Figure 3. The injection solenoid S (represented in the figures as its inductive winding) is usually connected to a system power supply V via a resistive shunt Rs, in parallel with a freewheel diode D. A conventional circuit 100 is included to measure current through the solenoid, the result of which is applied to a differencing component (shown as an operational amplifier 202) in a current-regulating circuit 200. Usually, this circuit 200 will have two inputs, namely, one to set the desired current level and another to turn the current on and off completely. The difference between measured current and desired current is then "added" into the circuit using a power transistor Q1. The On/Off signal is similarly applied via a corresponding transistor Q2, which acts essentially as a switch.

The source of the input signals for current level and current ON/OFF will typically be a supervisory processor that calculates desired values and times and generates the input signals in digital form, which are the converted into analog form using a conventional digital-to-analog converter.

The reason that the voltage U to the solenoid circuit is pulsed ON/OFF in the prior art, instead of being controlled over a continuous range is that the power that develops in the control electronics becomes too high. The problem to be solved is therefore how to ensure a sufficiently large BIP window, thereby allowing reliable BIP detection, without too much power being developed in the circuitry. One known attempted solution to this problem is to include additional circuitry that adds voltage directly to the free-wheeling circuit. The difficulties and complications associated with this solution are well known.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 illustrates the current and voltage sequence used to control a solenoid in a fuel-injection system according to the prior art.

Figure 2 illustrates the current and voltage sequence used to control the solenoid using the invention.

Figure 3 shows the main components of a circuit for regulating current to control the solenoid in the prior art.

Figure 4 shows the main components of a circuit for regulating current to control the solenoid according to the invention.

DETAILED DESCRIPTION

Figures 2 and 4 illustrate the main idea, and circuit, respectively, of the invention: Instead of simply pulsing the control voltage U either ON (Umax) or OFF (0) using the current control circuit 200, additional voltage Uw that may lie and vary anywhere between Umax and 0, inclusive, is added into the solenoid circuit at the beginning of and maintained during the BIP window by a *voltage*-control circuit 300.

As Figure 4 shows, the voltage-control circuit 300 has a structure similar to that of the current control circuit 200, but taps the solenoid circuit directly (at the connection of the

freewheeling diode D and the solenoid) as an input to the differencing component 302. The input signals to the control circuit 300 are then the desired *voltage* level and *voltage* On/Off, which may also be generated by existing supervisory processing circuitry.

The "window voltage" Uw is shown in Figure 2 as being a constant voltage only by way of example. As will become clearer from the description below, the voltage control circuit may be used to generate any voltage profile during the BIP window. A constant additional voltage Uw, will, however, usually be sufficient to adjust the duration of the BIP window. The regulation of the current in the transition range between pull-in and hold is referred to here as "linear" regulation. In this context, linear regulation means that the voltage applied by the voltage-regulating circuit 300 according to the invention may take *any* value between 0 and the maximum supply voltage. This contrasts with the conventional ON/OFF (switched) regulation used it the prior art, which is illustrated in Figure 1.

As Figure 2 shows, applying the window voltage across the solenoid after the pull-in current has been shut off allows the circuit to control the rate at which the current decreases substantially arbitrarily. Because this added current during the BIP window may be controlled smoothly, there is no concern that the BIP pulse itself will disappear in the noise created by the regulation of the current. Furthermore, although the power developed in the control electronics may become relatively high during the phase of linear regulation, it will be so only briefly, so that the average power developed will still be low.

In order to ensure the ability to detect BIP with respect to all external circuits, there should be a certain minimum width of the BIP window. Figure 2 illustrates how the invention solves this problem using voltage-controlled linear regulation. One effect of the application of the invention is apparent from Figure 2, namely, the BIP window is lengthened. The voltage level that is applied during the current decay period (the BIP window) may also be determined in such a way that the time it takes for the current to decrease from the pull-in level to the hold level remains essentially constant, regardless

of the resistances within the network of conductor or other factors that might otherwise affect it.

As is mentioned above, if there were no resistive losses in the solenoid circuit, freewheeling could theoretically continue forever. In order to compensate for the voltage drop caused by the free-wheel current, multiplied by the inherent resistances, the invention thus makes it possible to add volts to the circuit.

Note that the figures principally show the principle of regulation -- in actual implementation, both of the control circuits 200, 300 may share the same power transistors and do not necessarily need separate ones. In such case, only a few small and simple components will be needed, which makes for a compact and inexpensive solution.

The voltage regulation according to the invention is shown here relative to ground. In those cases where the supply voltage varies greatly, however, the regulation preferably takes place relative to the supply voltage instead.

There are several main advantages of the invention: It ensures that one, using existing equipment, may determine with certainty when the solenoid core is being moved; in other words, one can determine exactly when fuel injection begins in a cylinder. This solution according to the invention means that one may in all cases achieve a well-defined window within which to detect the BIP substantially free of interference. Movement of the solenoid armature may then be detected accurately by the "bump" on the current curve, which is easy to detect using known techniques given the time made available by the invention for detection. This is in turn a prerequisite for exactly controlling and regulating a motor in order to minimize exhaust. The invention thus makes it possible to exactly control and regulate the fuel-injection time in a simple and cost-effective manner. The invention also makes it possible to allow greater resistances within the freewheel circuit, which means in turn that one can use cables of smaller gauge, which are less expensive.

CLAIMS

1. Method for solenoid control comprising the following steps:

- providing a freewheel circuit comprising a solenoid (S), connected to a system power - supply (V) via a resistive shunt (Rs) and a freewheel diod (D) in parallel with said solenoid (S), and said resistive shunt (Rs),
- providing a conventional circuit (100) measuring current through said solenoid (S),
- providing a current regulating circuit (200) comprising a differencing component (202), a power transistor (Q1) and a switch device (Q2),
- supplying a voltage pulse to said freewheel circuit by means of said power supply (V), to reach a predetermined current level in said solenoid (S), thereafter,
- supplying pulsed voltage to said freewheel circuit by means of said current regulating circuit (200),
- applying the measured result from said conventional circuit (100) to said differencing component (202)

maintaining said supply by means of said current regulating circuit (200) for a certain time based upon the result of said measurement

c h a r a c t e r i z e d in the further steps of,

providing a voltage control circuit (300) comprising a second differencing component (302) and a structure similar to that of said current control circuit (200),

connecting the input to said second differencing component (302) to the output from said current control circuit (200),

applying into said freewheel circuit by means of said voltage regulating circuit (300) a supply voltage of, any value between 0 and a maximum supply voltage, in order to control the rate at which the current within said freewheel circuit decreases.

2. Method according to claim 1, c h a r a c t e r i z e d in that an irregularity in the decrease of the current in said solenoid (S) is detected during said controlled decrease of current, in order to exactly determine when the solenoid core is being moved.

3. Method according to claim 2, c h a r a c t e r i z e d in that solenoid core moves a solenoid valve for fuel injection, in vehicle engine.

ABSTRACT

This invention relates to a method for solenoid control comprising the following steps:

- providing a freewheel circuit comprising a solenoid (S), connected to a system power - supply (V) via a resistive shunt (Rs) and a freewheel diod (D) in parallel with said solenoid (S), and said resistive shunt (Rs),
- providing a conventional circuit (100) measuring current through said solenoid (S),
- providing a current regulating circuit (200) comprising a differencing component (202), a power transistor (Q1) and a switch device (Q2),
- supplying a voltage pulse to said freewheel circuit by means of said power supply (V), to reach a predetermined current level in said solenoid (S), thereafter,
- supplying pulsed voltage to said freewheel circuit by means of said current regulating circuit (200),
- applying the measured result from said conventional circuit (100) to said differencing component (202)

maintaining said supply by means of said current regulating circuit (200) for a certain time based upon the result of said measurement

characterized in the further steps of,

providing a voltage control circuit (300) comprising a second differencing component (302) and a structure similar to that of said current control circuit (200),

connecting the input to said second differencing component (302) to the output from said current control circuit (200),

applying into said freewheel circuit by means of said voltage regulating circuit (300) a supply voltage of, any value between 0 and a maximum supply voltage, in order to control the rate at which the current within said freewheel circuit decreases.

FIG. 1
(Prior Art)

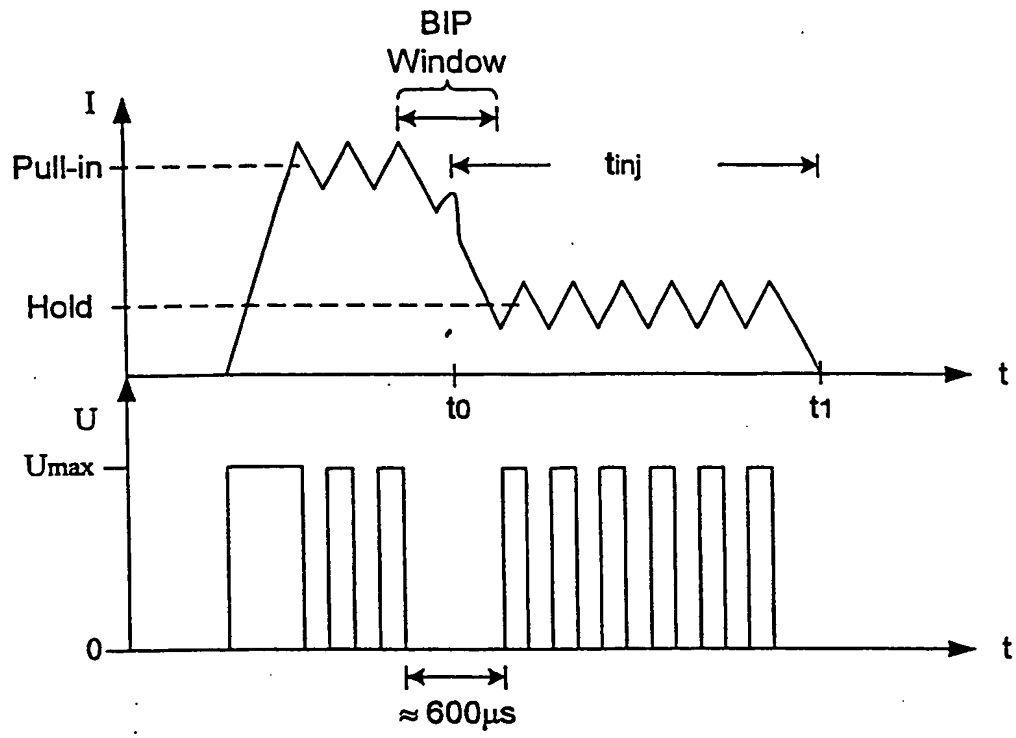
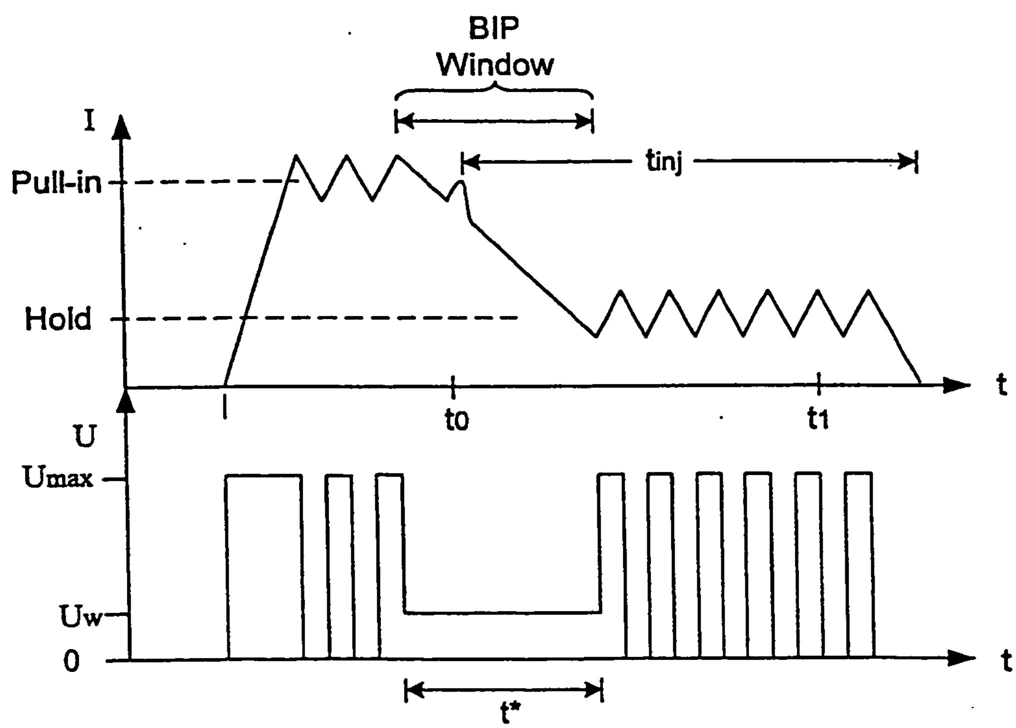


FIG. 2



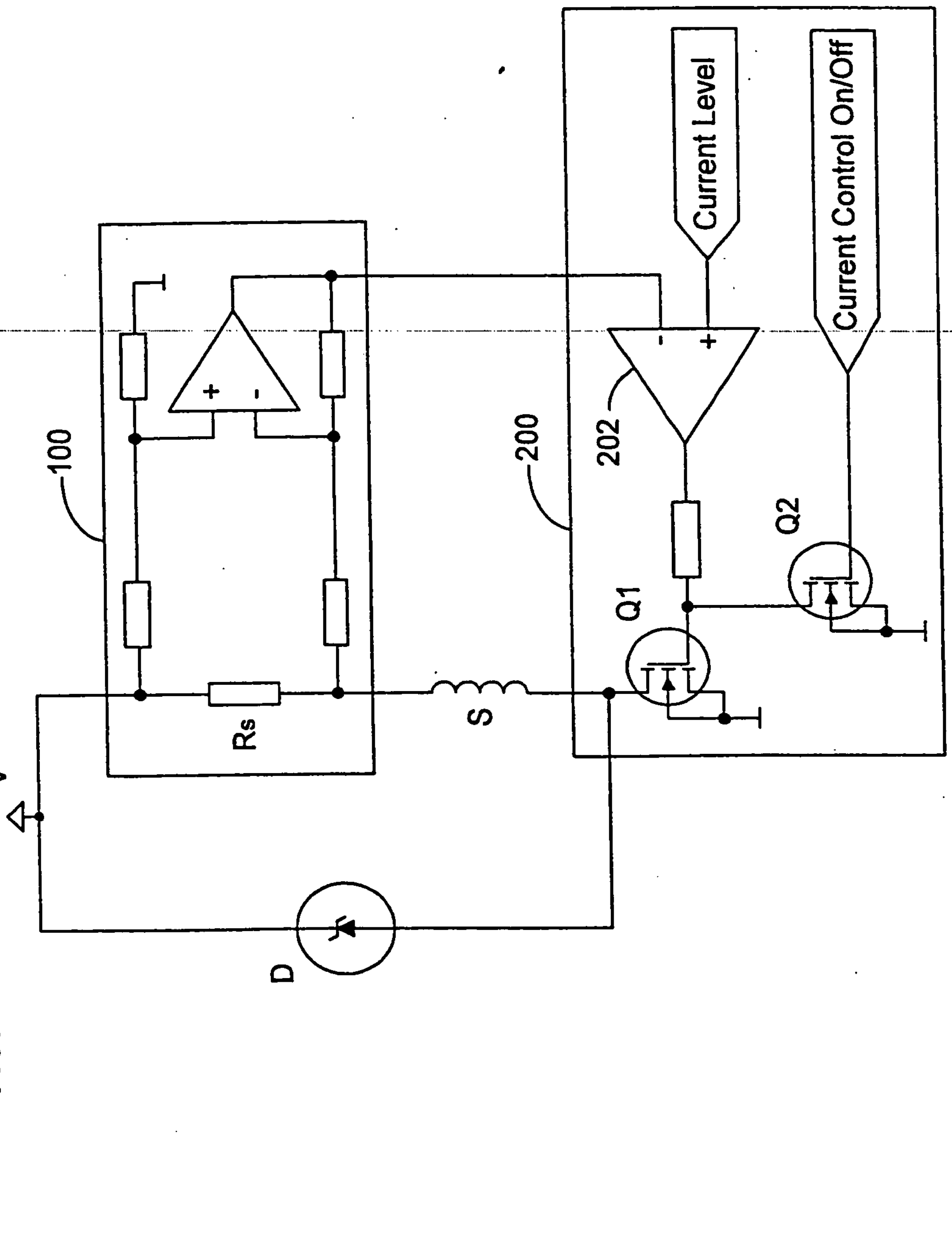
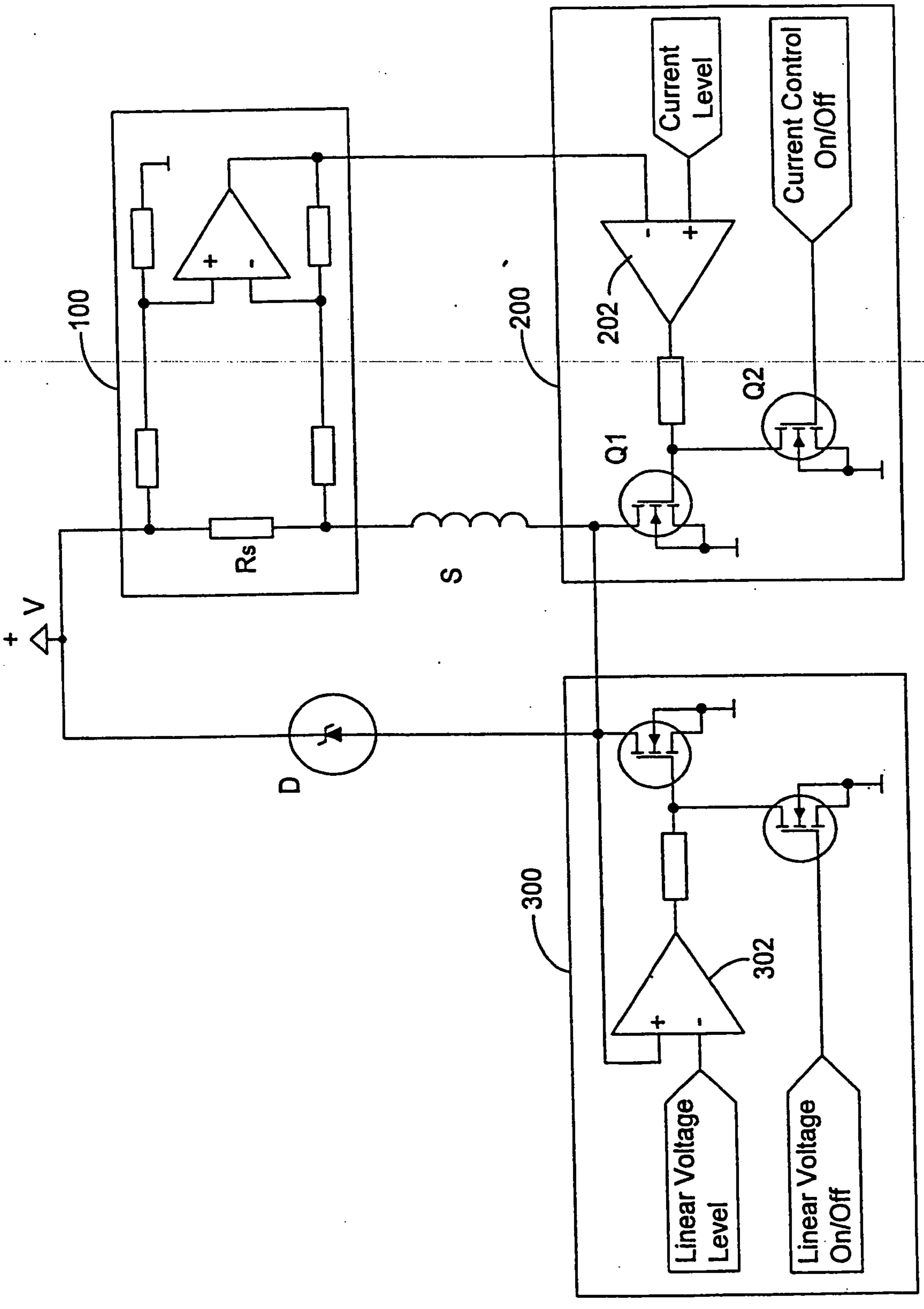


FIG. 3

FIG. 4


100
200
202
300
302
Rs
S
D
+ V
Q1
Q2
Current Level
Current Control On/Off
Linear Voltage Level
Linear Voltage On/Off